A new angle on printing

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Although blade contact angle is a critical stencil printing parameter, screen printers have so far been unable to vary it 'on-the-fly', in software. The recently released Assembléon/Yamaha YGP printer has changed this, and has made new application research possible to study a crucial 01005 process variable for feature printing that previous researchers have ignored.

We have designed the first robust solder paste printing process for 01005 components that uses only a single printer and stencil. We have studied transfer efficiencies across all the major parameters, with important results for reliable high-density equipment assembly. Our findings show that a variable blade contact angle can print fine features with wider process window, and reduce overall process variation between boards produced from a line.

Keywords: Screen Printing, Stencil, Blades, Blade Angle, Transfer Efficiency

Introduction

The challenge of successful 01005 feature solder printing has been well documented, driven by the continuing trend to miniaturize electronic assemblies. Successful implementation of this technology will demand critical improvements to the process, pushing beyond the limits of current technology.

One solution, which involves a large capital expenditure, is to use two printers and two stencils: one printer with a thin stencil to print the miniature components, and a second in-line printer with a thicker stencil to cover the larger solder paste volume requirements. A second, and more economical, solution would require process optimization and a very tight process window. This means identifying exacting process parameters, including circuit board fabrication (pad designs, etc.), stencil (fabrication method, thickness and aperture size), solder paste (particle size, rheology and activator robustness), printing parameters (speed, separation, pressure, etc.), placement (pressure, speed and accuracy etc.) and reflow optimization (atmosphere and thermal profile).

Improvements have been made over the years to most of the above process inputs. Various studies have evaluated fabrication methods, investigating, for example, electroform versus laser-cut and comparing the effect of stencil thickness. Stencil printing studies have regarded the effects of print speed, print pressure, and separation speed to optimize solder paste transfer efficiency (TE). However, one crucial area that has not been examined is the blade contact angle. In part, this is because printers cannot program a variable contact angle. The ability to change blade contact angle as a process parameter would greatly widen the process window for printing fine features.

Theory

Good quality in stencil printing ultimately means delivering the right amount of solder paste to the right place on the substrate. The final paste layer should be flat, with even thickness across the deposit and the correct shape (pattern resolution).

SMT stencil printers have two blade angle parameters: a static contact angle and a dynamic attack angle (*Figure 2*). The contact angle is a function of the blade holder and is formed between the stencil and blade, achieving contact with the stencil with no force between them. The attack angle is a function of the contact angle, blade compliancy, print speed and paste rheology; it is the sum of the static and dynamic forces acting on the blade during the print stroke. Although the dynamic attack angle is complicated to determine, it is primarily established by the static contact angle.

Earlier theoretical and applied research has demonstrated that solder paste rolling generates the downward force vector that fills the stencil aperture with paste. A fundamental requirement of solder paste printing is the generation of the correct amount of downward force in the paste roll to properly fill stencil apertures. Too little force and the aperture will not fill properly; too much force and the result is a premature breakdown of the solder paste. Our work shows

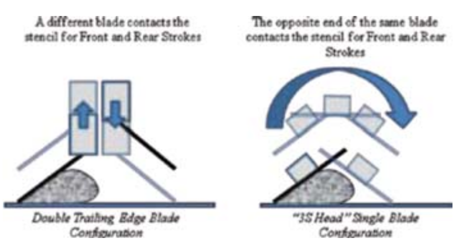

Figure 1. Comparison of the YGP 3S (Swing Single Squeegee) to the standard double trailing edge blade configuration.

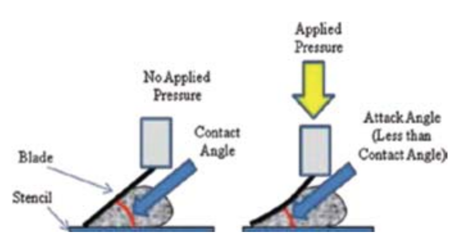

Figure 2. Contact angle vs. attack angle.

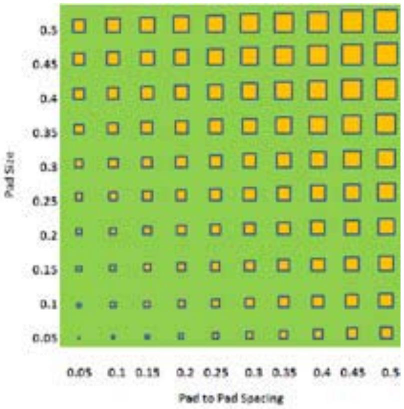

Figure 3: Test board design (all units in mm).

Run	Angle	Pressure
1	45	60
2	65	50
3	65	60
4	45	50
5	45	40
6	55	50
7	55	60
8	65	40
9	55	40
10	45	50
11	45	60
12	65	60
13	65	40
14	55	50
15	55	60
16	65	50
17	45	40
18	55	40

Figure 4. DoE setup.

the effect that varying the contact angle has on aperture fill and release.

Previously, the attack angle was the only blade angle that could be adjusted easily in production. The primary way of adjusting this angle is to increase or decrease the blade pressure, which in turn deflects the blade to a different angle. Using this method, limited adjustments can be made without adversely affecting the solder paste or the ability to wipe the top of the stencil clean. However, decoupling the attack angle from the blade pressure by changing the contact angle significantly improves the capability of the process.

Our study explored the effects of modifying the blade angle. We examined two variables in our testing: applied angle and attack angle.

Test methodology

We undertook a systematic structured DoE (design of experiment) to determine the effects of blade angle on print transfer efficiency. The two main factors were blade contact angle (45°, 55° and 65°) and print pressure (40N, 50N and 60N). For this experiment, we used Alpha Metals OM-338 CSP, an IPC type 4 (22 to 38 microns) lead-free solder paste with a 4 mil foil and an Assembléon YGP printer. Blade length was 350 mm and separation speed was held constant at 7 mm/sec over a distance of 2 mm.

For this test, we used a board and stencil with varying aperture sizes and spacing. All the test patterns used a 10 x 10 matrix of square apertures. These varied from 0.05 mm by 0.50 mm square, with 0.05 mm spacing between the apertures (*Figure 3*). These patterns were printed on a bare pad with ENIG finish. The test board was designed and patented by Research in Motion to yield both bridging and insufficient solder at the extremes, to allow for an objective measurement of the print quality.

Paste deposit measurements down to 0.2 mm were made with a GSI Lumonics 8200 3-D inspection system. This was the smallest deposit that could be robustly measured by this machine. Additional visual inspection was done below the 0.2 mm pad size to determine the smallest aperture and spacing that could be effectively printed at each of the test levels.

To reduce variation across the test, we attempted to keep the solder paste roll the same diameter by adding a small amount (~5 g) of solder paste every six boards. Six boards were printed for each condition, performing a vacuum wipe after the second board. Data were taken on boards 5 & 6 of each run. A cycle time of approximately 40 seconds was maintained throughout the experiment. The data were replicated in random order to yield the results. We analyzed the data from only one print stroke direction (front to rear stroke) to eliminate another potential source of variance.

Angle and pressure were varied in a full factorial experiment with a two replicates. The runs were randomized and coded, to minimize the effect of random error. The experiment was set up as described in *Figure 4*.

From our experience with a large CEM customer, acceptable yields have been achieved for 01005s in production using 0.170 mm square apertures with a 0.076 mm stencil. This results in an area ratio of 0.56 [AR= w/4T, where w = the width]. In light of this, we looked closely at the apertures that were around this value. In this test, the 0.25 mm, 0.20 mm and 0.15 mm square apertures yielded area ratios of 0.61, 0.49 and 0.37 respectively on a 0.101 mm thick stencil.

Results and discussions

The data were grouped by area ratio,

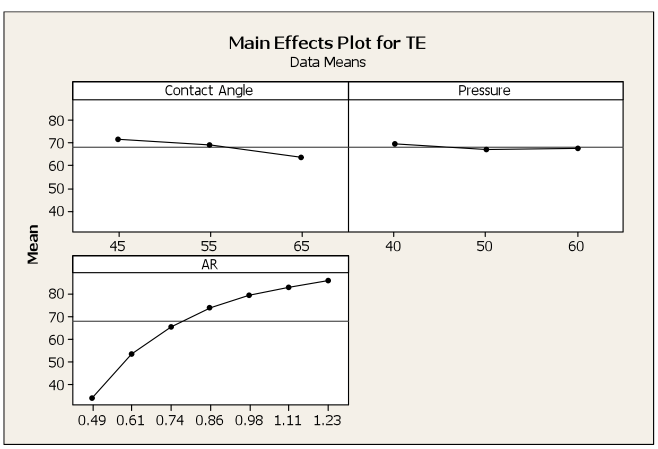

Figure 5. Main effects plot all data.

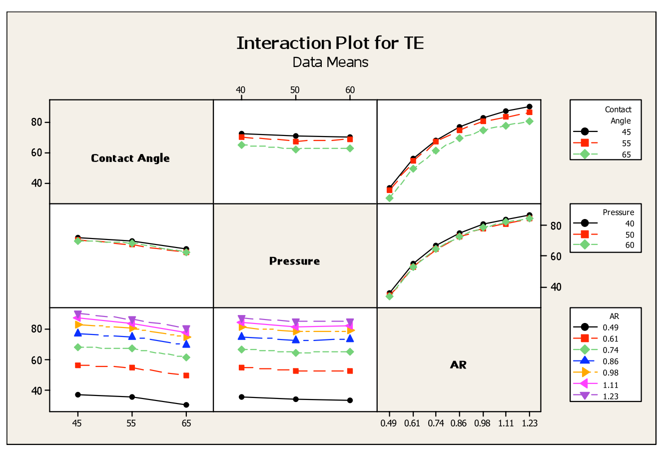

Figure 6. Interaction plot.

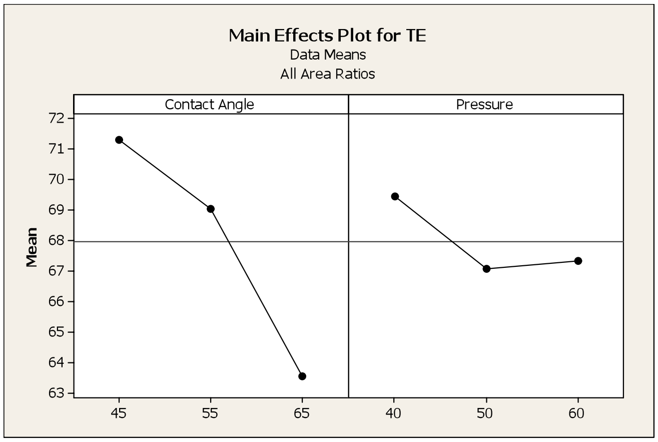

Figure 7. Main effects plot for all area ratios.

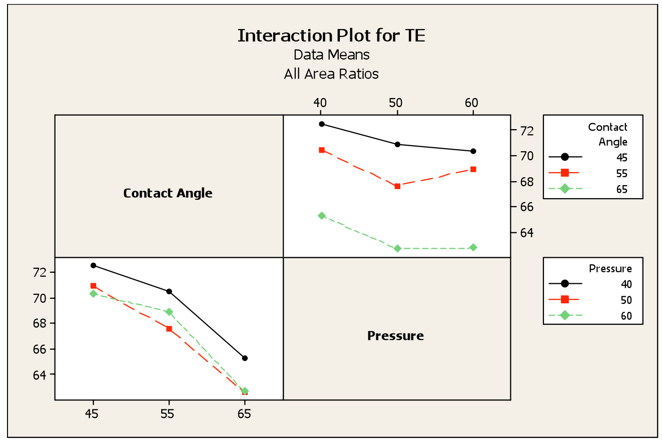

Figure 8. Interaction plot for all area ratios.

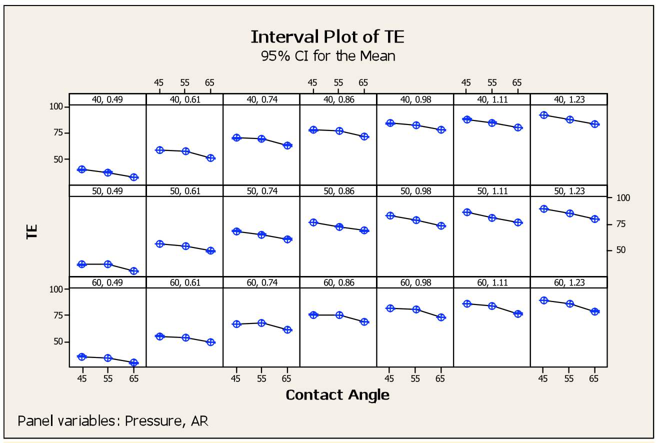

Figure 9. Interval plot of TE for all.

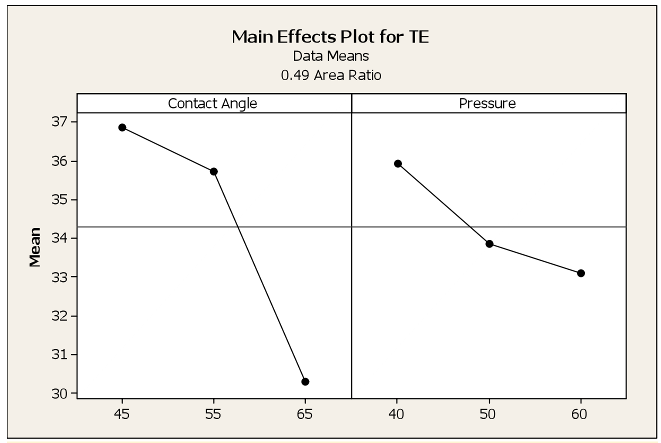

Figure 10. Main effects plot for 0.49 area ratio apertures.

discarding the data with less than 0.15 mm spacing, as this was prone to bridging, discerned by visual examination. This left seven sets of 100 data points for the 0.2 mm up to the 0.5 mm devices. A total of 176,400 solder paste deposits were measured.

The data were evaluated for transfer efficiency (TE), or the percentage of the theoretical maximum volume for the aperture in question. Our results are summarized in the charts.

Figure 5 shows that area ratio has the greatest impact on transfer efficiency.

Figure 6 shows no significant interactions between the contact angle, pressure and area ratio.

Board designers have a restricted amount of spacing around fine feature components. Once area ratio has been maximized under these limitations, further improvements to transfer efficiency can be made via contact angle and pressure optimization (*Figure 7*).

Figure 7 shows the main effects plot for transfer efficiency with contact angle and pressure being the factors. It can be seen that the lowest contact angle and lowest pressure give the greatest transfer efficiency, and that contact angle has a greater effect on transfer efficiency than pressure.

We noticed no significant interactions between contact angle and pressure on the transfer efficiency (*Figure 8*).

The slope of the TE vs. contact angle curve decreases with increasing pressure and decreasing area ratio (*Figure 9*). In other words, there is a smaller benefit in decreasing the contact angle at higher print pressures. *Figures 10* to *12* show details of the 0.49 area ratio.

We performed a visual inspection of pictures taken of all these patterns for the 0.15 mm pads with 0.15 mm spacing. These were labeled by run number only, in order to minimize analysis bias. Each unique combination of two boards was compared for transfer efficiency. The board with the greater transfer efficiency was given a score of +1, and the other a score of -1. These results were then added for all the combinations to achieve a final score for each board (*Figure 13*).

Data were then decoded and analyzed for the main effects of pressure and contact angle, shown in *Figure 14*.

Figures 15 and *16* respectively show an example of the best and the worst transfer efficiencies.

Conclusion

The tests led to four major conclusions:

1. Greater transfer efficiencies are obtained for the same area ratio by reducing the blade contact angle.
2. Increasing print pressure decreases the attack angle, but has a negative effect on transfer efficiency.
3. The best results were found at the lower limit of the DoE, although further testing is needed to determine if this is the true optimum. Experience shows that too low a pressure and too low an angle will cause solder paste to remain on the stencil, resulting in inconsistent and thicker prints.

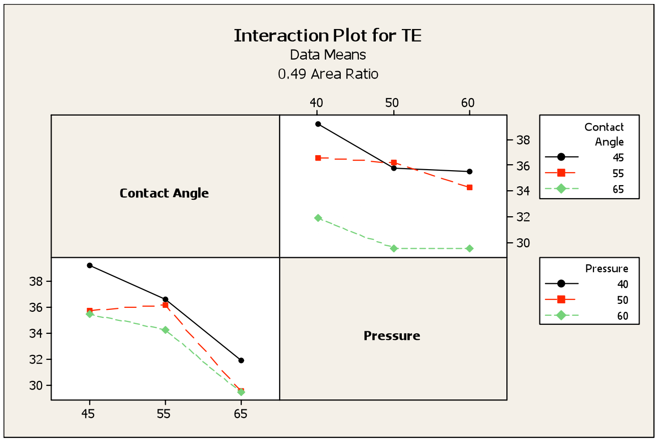

Figure 11. Interaction plot for 0.49 area ratio apertures.

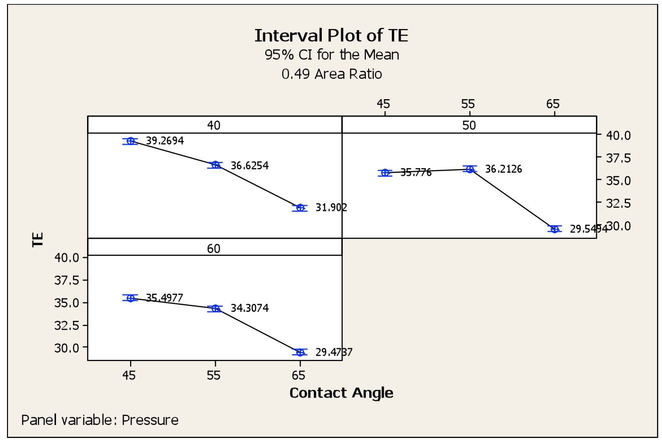

Figure 12. Interval plot for 0.49 area ratio apertures.

Board Number (columns) / Board Number (rows)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1		-1/1	-1/1	-1/1	-1/1	0/0	1/-1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1
2	1/-1		1/-1	1/-1	1/-1	1/-1	1/-1	-1/1	1/-1	1/-1	1/-1	-1/1	-1/1	1/-1	1/-1	0/0	1/-1	1/-1
3	1/-1	-1/1		1/-1	1/-1	1/-1	1/-1	-1/1	1/-1	1/-1	1/-1	-1/1	1/-1	1/-1	1/-1	-1/1	1/-1	0/0
4	1/-1	-1/1	-1/1		1/-1	1/-1	1/-1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	0/0	-1/1
5	1/-1	-1/1	-1/1	-1/1		1/-1	1/-1	-1/1	-1/1	-1/1	0/0	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1
6	0/0	-1/1	-1/1	-1/1	-1/1		1/-1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1
7	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1		-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	-1/1
8	1/-1	1/-1	1/-1	1/-1	1/-1	1/-1	1/-1		1/-1	1/-1	1/-1	1/-1	1/-1	1/-1	1/-1	1/-1	1/-1	1/-1
9	1/-1	-1/1	-1/1	1/-1	1/-1	1/-1	1/-1	-1/1		1/-1	1/-1	-1/1	-1/1	0/0	-1/1	-1/1	0/0	-1/1
10	1/-1	-1/1	-1/1	1/-1	1/-1	1/-1	1/-1	-1/1	-1/1		-1/1	-1/1	-1/1	-1/1	-1/1	-1/1	1/-1	-1/1
11	1/-1	-1/1	-1/1	1/-1	0/0	1/-1	1/-1	-1/1	-1/1	1/-1		-1/1	-1/1	-1/1	0/0	-1/1	1/-1	-1/1
12	1/-1	1/-1	1/-1	1/-1	1/-1	1/-1	1/-1	-1/1	1/-1	1/-1	1/-1		1/-1	-1/1	1/-1	-1/1	1/-1	1/-1
13	1/-1	1/-1	-1/1	1/-1	1/-1	1/-1	1/-1	-1/1	1/-1	1/-1	1/-1	-1/1		1/-1	1/-1	1/-1	1/-1	1/-1
14	1/-1	-1/1	-1/1	1/-1	1/-1	1/-1	1/-1	-1/1	0/0	1/-1	1/-1	1/-1	-1/1		-1/1	-1/1	0/0	-1/1
15	1/-1	-1/1	-1/1	1/-1	1/-1	1/-1	1/-1	-1/1	1/-1	1/-1	0/0	-1/1	-1/1	1/-1		-1/1	1/-1	-1/1
16	1/-1	0/0	1/-1	1/-1	1/-1	1/-1	1/-1	-1/1	1/-1	1/-1	1/-1	1/-1	-1/1	1/-1	1/-1		1/-1	1/-1
17	1/-1	-1/1	-1/1	0/0	1/-1	1/-1	1/-1	-1/1	0/0	-1/1	-1/1	-1/1	-1/1	0/0	-1/1	-1/1		-1/1
18	1/-1	-1/1	0/0	1/-1	1/-1	1/-1	1/-1	-1/1	1/-1	1/-1	1/-1	-1/1	-1/1	1/-1	1/-1	-1/1	1/-1	
Score	14	-10	-8	8	10	14	17	-17	1	5	3	-11	-11	-1	-2	-12	6	-6

Figure 13. Visual inspection results–comparison of 0.15 mm pads/0.15 mm spacing.

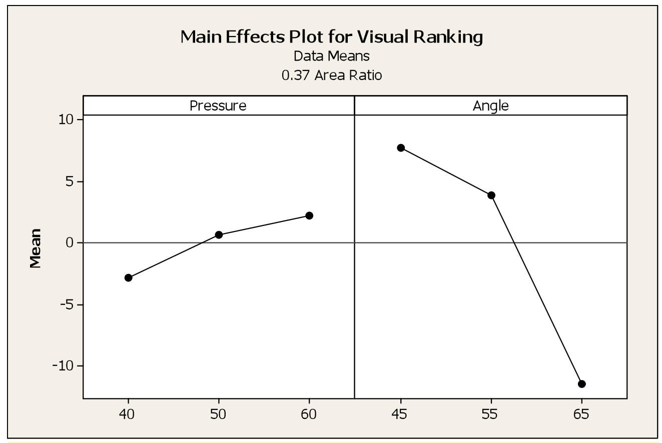

Figure 14. Main effects plot for visual ranking.

Another DoE is therefore in progress to further investigate the lower limit.

4. A lower area ratio can be used to print 01005s if the blade angle is optimized. This will allow designers to more efficiently place these components on a circuit board, or alternatively, allow SMT engineers to use a thicker stencil to print 01005s. Using a thicker stencil would in turn allow for a larger range of components on the PCB with a single print process and/or widen the process window for a diverse component set on a specific PCB.

Having the ability to program the contact angle, and vary it for different process requirements, is a valuable tool for the process engineer faced with these increasingly difficult challenges in SMT. The Assembléon YGP printer offers this functionality without requiring blade changes. This fact eliminates the potential for set-up errors, and allows for angle changes for different conditions, such as after a stencil wipe, breaks, or paste dispense.

This tool substantially refines the process for printing fine features. To further examine this, additional studies are planned to evaluate the effect of transfer efficiency while focusing on optimizing stencil thickness, evaluating type 3, 4 and 5 solder pastes, as well as optimizing pick & place and reflow processes. Once these studies are complete, we should be able to better characterize the overall 01005 process and have recommendations for an extensive range of process parameters.

Figure 15. Best transfer efficiency for 0.37 AR.

Figure 16. Worst transfer efficiency for 0.37 AR.

Assembléon is introducing a new screen printer, the YGP, for short cycle-time applications that varies the squeegee contact angle in software, depositing the exact amount of solder needed by each component.